Eur Radiol (2004) 14:1508–1512
DOI 10.1007/s00330-004-2332-2

PEDIATRIC

Sven C. Michel
Ishilde Forster
Burkhardt Seifert
Ulrich V. Willi
Thierry A. G. M. Huisman

Renal dimensions measured by ultrasonography in children: variations as a function of the imaging plane and patient position

Received: 16 December 2003
Revised: 5 March 2004
Accepted: 1 April 2004
Published online: 28 April 2004

S. C. Michel · I. Forster · U. V. Willi
T. A. G. M. Huisman (✉)
Department of Diagnostic Imaging,
University Children's Hospital Zurich,
Steinwiesstrasse 75, 8032 Zurich,
Switzerland
e-mail: thierry.huisman@kispi.unizh.ch
Tel.: +41-266-7110
Fax: +41-266-7158

S. C. Michel
Institute of Diagnostic Imaging,
University Hospital Zurich,
Zurich, Switzerland

B. Seifert
Department of Biostatistics,
University of Zurich,
Zurich, Switzerland

Abstract The purpose of this study was to determine the effect of patient positioning on sonographic renal measurements and to test if the patient position alters the three-dimensional shape of the kidneys. The maximum longitudinal renal length and transverse renal width and depth were measured in the supine and prone position in 100 children (200 kidneys). Age ranged from 6 months to 16 years (mean age 5 years). The results were compared for statistically significant differences. The maximum measured longitudinal renal length was statistically significantly larger in the supine than in the prone position (supine position, left: 8.0 cm; right: 7.7 cm; prone position, left: 7.9 cm, right: 7.6 cm; $P<0.001$). There was no statistically significant change in the transverse diameters (width and depth, $P>0.001$) and renal volume ($P>0.001$) in the supine vs. prone positions. Our results show that position-induced reshaping of the kidneys is unlikely to be responsible for the discrepancy in maximum longitudinal renal measurements comparing supine with prone positions. Position-dependent changes in the degree of filling of the renal calyces and pelvis as well as errors in caliper distance measurements for the different scan depths (supine vs. prone) are more likely to be responsible for the encountered differences. Consequently, we recommend to add prone renal length measurements in addition to the supine measurements. In follow-up examinations, renal length measurements should only be compared that have been collected in the same patient position.

Keywords Ultrasonography · Renal measurements · Patient positioning

Introduction

Measurement of renal dimensions (e.g., maximal renal length and calculated renal volume) plays an important role in the evaluation, identification and follow-up of renal pathology in children. Normative standards have been established that are correlated to the patient's age as well as to different somatic developmental parameters, including body length, body weight and body surface area [1–3]. Deviations of renal dimensions from these normative values may indicate renal disease. Ultrasonography is the modality of choice for measuring renal dimensions because it has proven to be accurate, can be performed bed-side, is readily available and can be applied repeatedly in children because no ionizing radiation is used [2–4]. Schlesinger showed, however, that variations in renal length can be measured that are equal to the normal increase in renal length that occur in 1–2 years, suggesting that ultrasonography is limited for evaluating renal growth [5]. In addition, several studies have shown that the measured maximal longitudinal renal length varies with the used imaging plane as well as with the patient position [3, 6–8]. De Sanctis and Nakamura showed that coronal views in the contralateral

Table 1 Renal dimensions as measured by ultrasonography. The left kidney is larger than the right kidney in the supine and prone position. Measurements marked with an asterisk are calculated for 100 children; all other measurements are calculated for 55 children. Length, width and depth dimensions are in cm, volume in cm^3. (SD, standard deviation)

	Supine, mean ± SD (range: minimun–maximum)	Prone, mean ± SD (range: minimun–maximum)
Left length*	8.0±1.8 (4.4–11.7)	7.9±1.8 (4.4–11.6)
Left length	7.9±1.8 (4.9–11.7)	7.7±1.7 (5.2–11.6)
Left width	3.7±0.9 (2.2–5.9)	3.7±0.8 (2.1–5.3)
Left depth	3.4±0.7 (2.2–4.9)	3.3±0.6 (2.2–4.8)
Left volume	57.0±35.5 (14.5–166.0)	54.3±32.3 (15.0–146.8)
Right length*	7.7±1.7 (4.6–11.4)	7.6±1.8 (4.3–11.7)
Right length	7.6±1.6 (4.6–11.3)	7.4±1.6 (4.4–10.8)
Right width	3.8±0.9 (2.2–5.9)	3.8±0.9 (2.5–5.9)
Right depth	3.3±0.6 (2.0–4.8)	3.2±0.7 (2.1–5.1)
Right volume	54.1±31.2 (15.5–144.5)	52.4±32.0 (14.1–153.4)

oblique position and sagittal views in the supine position yield longer renal lengths than sagittal views in the prone position [3, 7, 8]. Nakamura et al. suggested that these variations may be explained by subtle changes in the renal shape associated with the patient position [8].

The goal of our study is to test this hypothesis by measuring the maximal width and depth of the kidneys on a transverse section next to the maximal longitudinal length in the supine and prone positions. In addition, the influence of differences in scan depth (supine vs. prone position) on the accuracy of ultrasonographic length measurements is discussed.

Patients and methods

Between July and December 2002, 105 consecutive children who were referred for abdominal ultrasonography were prospectively studied. Children with a history of renal disease or suspected renal pathology on ultrasonography were excluded from the study. No routine urine sampling was performed in the children that were included in the study. The final study group included 100 children (200 kidneys) ranging in age from 6 months to 16 years. The mean age was 5 years and median age 4 years 8 months. Three children had to be excluded because of suspected renal pathology on ultrasonography; in two children no valid renal measurements could be obtained because of severe scoliosis and overlying bowel gas. All examinations were performed by the same experienced ultrasonographer (SM). The maximum longitudinal bipolar length of the kidneys was measured in the supine position by flank measurements with the transducer positioned in the ipsilateral mid-axillary line (coronal plane) and in the prone position with a posterior transducer approach (sagittal plane). The maximum longitudinal length of the kidney was visually estimated to represent the largest longitudinal section at the level of the renal hilum (100 children, 200 kidneys). The maximum width and depth (thickness) were measured in a transverse plane perpendicular to the longitudinal axis of the kidney at the level of the renal hilum in the supine and prone position (55 children, 110 kidneys). Width and depth were measured in orthogonal planes. These standardized planes in renal biometry are similar to those previously published [1]. Measurements were made on a freeze-frame image during the real-time examination by manually positioning electronic calipers in the image. Measurements were repeated or excluded if for any reason the kidney boundaries were uncertain (i.e., renal contour partially obscured by bowel gas, interposed scars, dressings or tubes) or in cases where the entire length of the kidney could not be included in the field of view, as in children with large or superficially located kidneys. Imaging was performed with either a Sequoia 512 (Acuson, Mountain View, CA) or a HDI 5000 (ATL Ultrasound, Bothell, WA) scanner. The transducer chosen was the one that allowed best visualization of the kidneys in the designated imaging planes and patient position and size. In all cases, the used transducer frequency ranged between 5 and 8.5 MHz. In all cases, a curved array transducer was used. The time period between supine and prone measurements was kept as short as possible to minimize dynamic physiologic phenomena that can influence renal size (e.g., increasing bladder filling or differences in hydration).

Previous studies showed that no sex differences have been seen in renal biometry, consequently all data were rearranged without being separated according to sex [1, 2]. Data for right and left kidneys were analyzed separately because the left kidneys are generally slightly larger in median length than the right kidneys [1]. The mean and standard deviation of the individual renal measurements generated from the different imaging planes were calculated. In addition, the mean of the absolute value of the differences between the individual renal measurements from the different imaging planes were calculated.

Finally, the renal volume was calculated using the ellipsoid formula: volume = length × width × thickness × $\pi/6$ [4, 9]. Measurements and calculated volumes are presented as mean ± standard deviation. For statistical analyses, they were logarithmized for homogenization and approximation of normal distribution. A paired t-test was used to compare the right with left kidney as well as supine with prone measurements. Linear regression was used for correlation of the transformed measurements. The Mann-Whitney U-test was used to exclude a possible influence of the used equipment and age distribution. Because all measurements were performed as part of the routine ultrasound protocol, no separate informed consent was taken for the presented study.

Results

The renal length, width and depth measurements for the supine and prone position are summarized in Table 1. As expected, the mean maximum bipolar longitudinal length was statistically significantly larger for the left kidney compared to the right kidney in both positions (supine position, left kidney: 8.0 cm; right kidney: 7.7 cm and prone position, left kidney: 7.9 cm, right kidney: 7.6 cm; paired t-test for transformed data, n=100; supine $P<0.001$, prone $P<0.001$). The calculated volumes of the left kidney were larger than those of the right kidney in both positions; the differences, however, were not statistically significant. Linear regression analysis showed a strong correlation between the supine and prone longitu-

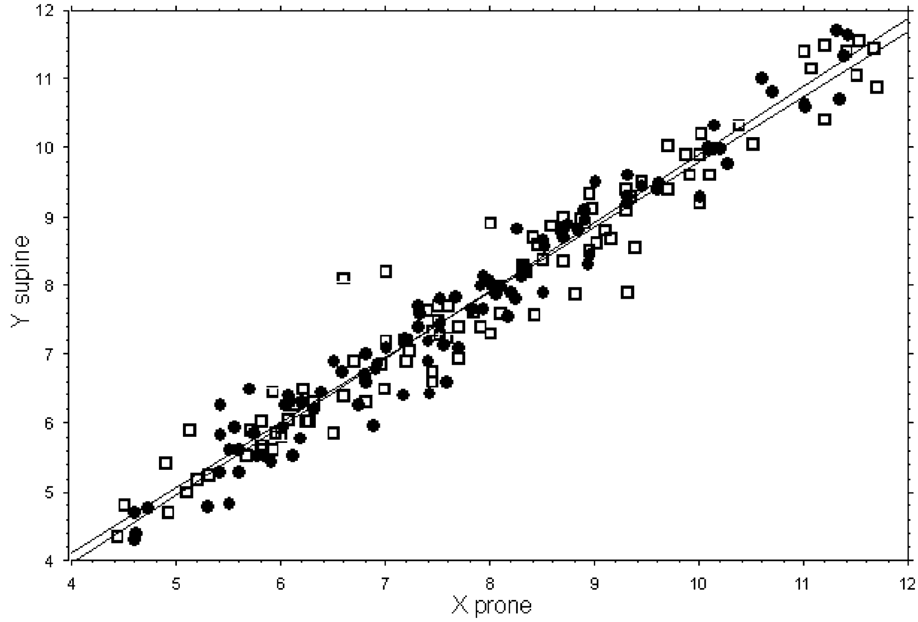

Fig. 1 Linear regression between the logarithmized supine and prone longitudinal measurements for both kidneys (left kidney: r^2=0.943, P<0.001; right kidney: r^2=0.951, P<0.001, n=100). *Open squares* refer to the left kidney, *closed dots* to the right kidney

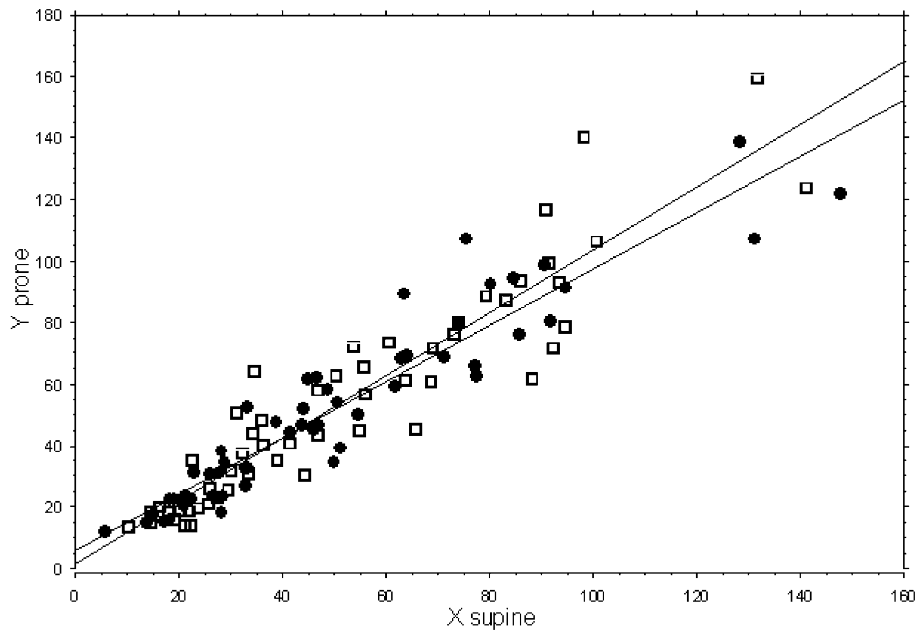

Fig. 2 Linear regression between the logarithmized supine and prone renal volumes (left kidney: r^2=0.879, P<0.001; right kidney: r^2=0.902, P<0.001; n=55). The variation of the volume data around the regression line reflects the limited reliability of volume calculations based on the ellipsoid formula. *Open squares* refer to the left kidney, *closed dots* to the right kidney

dinal measurements for both kidneys (left kidney: r^2=0.943, P<0.001; right kidney: r^2=0.951, P<0.001, n=100). There was also a strong correlation between the supine and prone renal volumes (left kidney: r^2=0.879, P<0.001; right kidney: r^2=0.902, P<0.001; n=55) (Figs. 1, 2).

The differences between the individual renal measurements for the supine and prone position are shown in Table 2. The measured maximum bipolar longitudinal renal length was statistically significantly larger in the supine position compared to the prone position (n=100). The left kidney was 0.11 cm larger in the supine position compared with the prone position (P=0.03). The right kidney was 0.08 cm larger in the supine position than in the prone position (P=0.02). There was neither a statistically significant difference (n=55) comparing supine with prone depth and width measurements nor for the calculated supine and prone renal volumes. There was no difference in renal length measurements (Mann-Whitney test: right kidney P=0.7, left kidney P=0.6) or age distribution (P=0.5) for the two ultrasonography units.

Table 2 Mean differences of the logarithm in renal dimensions comparing supine and prone position for both kidneys. Statistically significantly larger kidneys are measured in the supine position compared to the prone position. There are no statistically significant differences of renal width, depth and volumes. Measurements marked with an asterisk are calculated for 100 children; all other measurements are calculated for 55 children. Length, width and depth differences are in cm, volume differences in cm^3 (SD, standard deviation). A *P*-value <0.05 was considered to be statistically significant

	Left kidney		Right kidney	
	Mean diff. ± SD	*P*-value[a]	Mean diff. ± SD	*P*-value[a]
Supine vs. prone length*	0.11±0.43	0.030	0.08±0.36	0.024
Length	0.13±0.36	0.029	0.12±0.38	0.031
Width	–4.07±1.09	0.391	0.02±0.50	0.807
Depth	0.11±0.49	0.138	0.06±0.38	0.246
Volume	2.70±13.07	0.353	1.70±11.05	0.124

[a] Paired *t*-test supine vs. prone for log-transformed measurements.

Discussion

Ultrasonographic measurements of kidney length and comparison with standardized growth charts on normal kidney development are widely accepted as a reliable, non-invasive tool in the evaluation and follow-up of renal disease. Ultrasonography is especially well suited for the evaluation of renal pathology in children because it lacks ionizing radiation and can consequently be used as often as necessary to assess renal growth over time. In addition, ultrasonography is widely available, can be performed bed-side, is non-expensive and is well accepted by parents and children. Making renal length measurements may appear easy. Unfortunately, the accuracy and reproducibility of ultrasonographic length measurements are influenced by many factors, including patient-, examiner- and equipment-related variables. Sargent and Wilson [10] and Schlesinger et al. [5] found observer variations that were equal to the normal increase in renal length that occurs in 1–2 years. These variations are especially troublesome in repetitive examinations in which the dynamics of renal disease are evaluated by assessment of renal size and growth over time. The poor accuracy and repeatability of renal measurements may be due to inadequate depiction of the renal borders, e.g., by overlying bowel gas, ribs, interposed scars or patient motion. Furthermore, several reports have shown that, depending on the patient position, the measured maximal longitudinal length varies. Carrico, De Sanctis and Nakamura showed that supine, coronal views yield longer renal measurements than prone, sagittal views [3, 6–8]. Carrico and De Sanctis did not propose an explanation for the reported position-related differences. Nakamura suggested that subtle changes in kidney shape associated with position might explain these variations in part. If this hypothesis is correct, it would be expected that a larger maximal longitudinal length in the supine position would be accompanied by a smaller transverse depth and/or width of the kidney. Our study results confirmed the previous study results by showing a statistically significant larger maximal longitudinal renal length in the supine, coronal imaging plane compared to the prone, sagittal imaging plane. The transverse diameters, however, paralleled the longitudinal measurements; the renal width and depth were larger in the supine than in the prone position. However, these changes were not statistically significant. The calculated renal volumes were also larger in the supine than in the prone position. These findings do not support the thesis that the change in position may reshape the three-dimensional (3D) renal architecture.

An alternate explanation for the discrepancy in the measured maximal longitudinal renal lengths may be position-dependant variations in the filling degree of the renal collecting system. It is well known from excretory urography that in the supine position, contrast pools in the calyces and may outline the renal pelvis, while in the prone position, contrast flows from the calyces into the more anteriorly situated renal pelvis and ureter. Consequently, the renal pelvis will be less filled and/or distended [11, 12]. This shift of urine from the calyces into the ureter may at least partially explain the difference in all three renal dimensions.

Errors in the accuracy of ultrasonographic caliper measurements of distance may also in part explain the discrepancy in the measured renal lengths. In 2D ultrasonography, limits on precision of caliper placement lead to errors in estimating distance equal to about 0.25% of the full-scale display scan length or field of view. Because the image depth of the kidney is different for the supine position compared to the prone position, a different degree of error in the caliper measurements of distance will occur [13]. Riccabona documented a maximal error of 2% for distance measurements in 2D ultrasonography [9]. Finally, rotational and positional changes in the kidney because of changes in the patient position and/or changes in the degree of inspiration/expiration may also influence the accuracy of distance measurements.

In our study, we believe that the short time interval between the supine and prone measurements prevented physiologic changes in renal size (e.g., increasing bladder fullness). None of the children emptied the bladder between both imaging planes.

A limitation of our study is that the measurements were not performed at a standardized degree of inspiration or expiration. In addition, the 2D character of the ultrasonography measurements does not allow a reliable volume calculation, because the ellipsoid formula systematically underestimates renal volume because the kidneys are not a true ellipsoid [4].

At our department, prone studies are routinely performed for serial length measurements (in addition to supine measurements) because these views usually allow a better identification of the upper and lower renal borders that may not be seen as well on supine views.

Previous studies concluded that renal pathology is better expressed by renal volume than by outer kidney parameter and support the need for the further development of 3D ultrasound that allows a more accurate evaluation of the renal volume [1, 4]. A recent study published by Riccabona showed that 3D ultrasound is feasible in neonates, infants and children without the need for sedation. Riccabona showed that 3D ultrasound improves volume assessment and follow-up comparison by offering an improved standardization and documentation of the measurements. 3D ultrasound proved to be especially advantageous in the analysis of complex anatomical urogenital malformations or pathologies [14].

Conclusion

We confirm the findings from previous studies that the maximum measured longitudinal renal length is larger in the supine, coronal imaging plane than in the prone, sagittal imaging plane. We extend the previous studies by concluding that no statistically significant positional changes occur in the transverse, renal depth and width measurements. This finding makes it very unlikely that position-induced changes in renal shape are responsible for these differences in renal length measurements. Errors in the accuracy of caliper measurements with different image depths for supine and prone measurements may explain the observed differences in addition to a position-induced shift of urine from the renal calyces to the ureters. In follow-up examinations, renal length measurements should only be compared to those that have been collected in the same patient position. In our experience, we recommend to add prone length measurements in addition to the supine measurements, because the renal upper and lower borders are usually better depicted in the prone position. In future, 3D ultrasonography should give more reliable volume measurements.

References

1. Dinkel E, Ertel M, Dittrich M, Peters H, Berres M, Schulte-Wissermann H (1985) Kidney size in childhood. Sonographical growth charts for kidney length and volume. Pediatr Radiol 15:38–43
2. Konus OL, Oezdemir A, Akkaya A, Erbas G, Celik H, Isik S (1998) Normal liver, spleen, and kidney dimensions in neonates, infants and children: evaluation with sonography. Am J Roentgenol 171:1693–1698
3. De Sanctis JT, Connoly SA, Bramson RT (1997) Effect of patient position on sonographically measured renal length in neonates, infants and children. Am J Roentgenol 170:1381–1383
4. Bakker J, Olree M, Kaatee R, de Lange EE, Moons KGM, Beutler JJ, Beek FJA (1999) Renal volume measurements: accuracy and repeatability of US compared with that of MR imaging. Radiology 211:623–628
5. Schlesinger AE, Hernandez RJ, Zerin JM, Marks TI, Kelsch RC (1991) Interobserver and intraobserver variations in sonographic renal length measurements in children. Am J Roentgenol 156:1029–1032
6. Carrico CWT, Zerin JM (1996) Sonographic measurement of renal length in children: does the position of the patient matter? Pediatr Radiol 26:553–555
7. Nakamura M, Taniguchi N, Kawai F (1993) Sonographic study of renal length measurement difference in positions. Jpn J Pediatr Nephrol 6:241
8. Nakamura M, Itoh K (1998) Renal length changes with position. Pediatr Radiol 28:197
9. Riccabona M, Nelson TR, Pretorius DH (1996) Three-dimensional ultrasound: accuracy of distance and volume measurements. Ultrasound Obstet Gynecol 7:429–434
10. Sargent MA, Wilson BPM (1992) Observer variability in the sonographic measurement of renal length in childhood. Clin Radiol 46:344–347
11. Berdon WE, Baker DH, Leonidas J (1968) Advantages of prone positioning in gastrointestinal and genitourinary roentgenologic studies in infants and children. Am J Roentgenol Radium Ther Nucl Med 103:444–455
12. Riggs W, Haggod JH, Andrews AE (1970) Anatomic changes in the normal urinary tract between supine and prone urograms. Radiology 94:107–113
13. Acuson User Manual, Acuson Sequoia 512 Ultrasound system (1999) Acuson Corporation, Mountain View, 7-4
14. Riccabona M, Fritz G, Ring E (2003) Potential applications of three-dimensional ultrasound in the pediatric urinary tract: pictorial demonstration based on preliminary results. Eur Radiol 13:2680–2687